

Validation of magnetocardiographic current density imaging with a non-magnetic stimulation catheter

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1 Introduction

Progress in revascularization treatment of coronary artery disease (CAD) have triggered a growing interest for new non invasive imaging and localization of myocardial ischemia and viability [1-3]. Most recently magnetocardiographic (MCG) source imaging has received increasing attention for that purpose, as demonstrated by the relevant number of papers presented at this conference. Different MCG parameters and indexes have been proposed to detect and localize myocardial ischemia. Although the investigation protocols and the analytic methods used by various authors are still widely different, the results seem to confirm that MCG mapping at rest and under effort contains diagnostic information additional to ECG [4-7].

Among different approaches the current-density estimation (CDE) method, by estimating the primary current distributions underlying MCG signals measured from patients suffering from acute or chronic ischemia, provides imaging and localization of ischemic injury current distribution [8-11]. On the other hand CDE has been also applied to localize malignant ventricular tachycardia [12]. Thus such ability to locate current sources, combined with precise timing of events, might be valuable in correlating the pathogenesis injury current-induced arrhythmias with ischemic events. However no systematic validation study on the localization accuracy of CDE was available so far.

In this study we have used the amagnetic catheter (AC) stimulation technique [13] to evaluate, in patients, the accuracy of current density imaging on the epicardial surface in localizing intracardiac current distribution and discriminating different simultaneous active cardiac sources. The results were compared with those of a parallel computer simulation study [8]. Goldstandard to test the accuracy of CDE was the localization of the distal terminal of the same amagnetic catheters with the Equivalent Current Dipole (ECD) inverse solution [13-15].

2 Methods

2.1 Patients

Out of 15 patients which underwent MCG mapping during right ventricular pacing with the amagnetic catheter technique [13] in the HUCH BioMag Laboratory, the MCG data of three patients were selected for this study. The amagnetic catheter induced point-like dipolar sources in the heart. In all patients the three-dimensional (3D) coordinates of the distal terminal of the catheters had been previously calculated from MCG mapping data with the ECD inverse solution and compared with their actual position, as inferred by multiple ortogonal fluoroscopic images of the patient's heart, taken in the EP cardiac catheterization laboratory [15]. In two patients (#538 and #541), two amagnetic catheters had been simultaneously inserted in the right ventricle, at the apex and at the mid anterior or septal wall, with their distal terminals about 3 cm apart and at about 5 to 8 cm depth from the sensors. The ECD 3D localization errors of the distance between the two catheters were minimal (6.1 and 0.9 mm respectively). Thus the set of MCG data used for the study were optimal to test, in patients, the accuracy of CDE and localization of point-like shallow sources. In the third patient (#162) a single amagnetic catheter was inserted in the coronary sinus, to test the accuracy of CDE for deep sources.

2.1 Current density imaging

The current density estimation (CDE) method was applied to solve the cardiomagnetic inverse problem, approximating the primary current distribution with dipolar elements, as described in more details elsewhere in this volume [8]. Solving the inverse problem with a distributed source model leads to an *ill-posed* problem, which implies that small amount of perturbation (noise, errors in the volume conductor model etc.) in the MCG data tends to be magnified in the inverse solution. Due to *ill-posed* problem regularization methods needed to be applied. In this study, zero- and second-order Tikhonov regularization methods in constructing

current density images were compared. Individualized torso models were constructed from magnetic resonance images. CDE was computed at the peak of the artificial catheter-induced dipole and/or during evoked myocardial depolarization.

3 Results

The results showed that CDE can localize both shallow and deep sources, but that the regularization method applied in the calculation will have to be selected carefully. Examples of CDE of catheter dipoles placed in the right ventricle and in the coronary sinus are given in Fig. 1, Fig. 2 and Fig. 4. In Fig. 3 the 3D localization of the distal terminals of the two amagnetic catheters, obtained with the equivalent current dipole inverse solution, in the same patient of Fig. 2, is shown for comparison.

For CDE of point-like (dipolar) sources, the second-order Tikhonov regularization was superior to the zero-order regularization because it localized both shallow and deep sources. However the zero-order regularization was more accurate in focusing shallow point-like sources (Fig. 1 and Fig. 2a), especially when iterative weighted method was used.

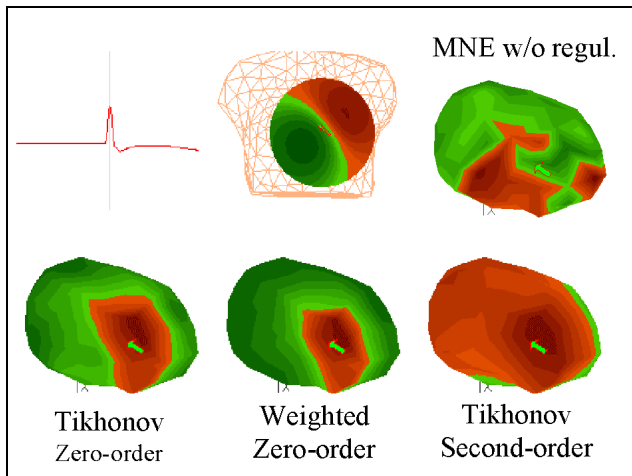


Figure 1: Patient # 541. Frontal views of magnetic field distribution (upper middle) and Current Density Imaging of a catheter-induced shallow source (10 μ A dipole in the middle right ventricle) Comparison between results obtained without regularization (upper right) and with zero-order, weighted zero-order and second-order Tikhonov regularization methods.

On the contrary the second-order regularization yielded an accurate description of the underlying current source configuration generated both by the shallow (Fig. 2b) and deep sources (Fig. 4b).

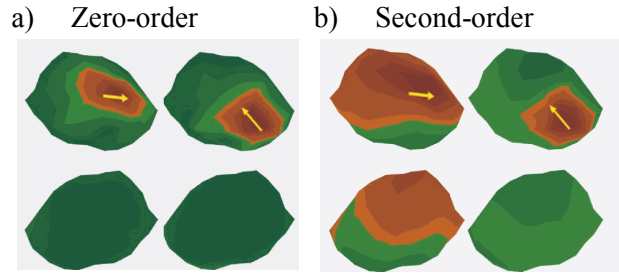


Figure 2: Patient # 538. Frontal (upper strips) and posterior (lower strips) views of epicardial surface. Current Density Imaging of catheter-induced shallow sources in the right ventricle, placed at mid-anterior wall (left in each box), and at the apex (right). Comparison between results obtained with a) zero-order and b) second-order Tikhonov regularization methods. Catheter sources were point-like dipoles. In this case zero-order performs better than second-order regularization, which spreads the pattern also to the posterior wall.

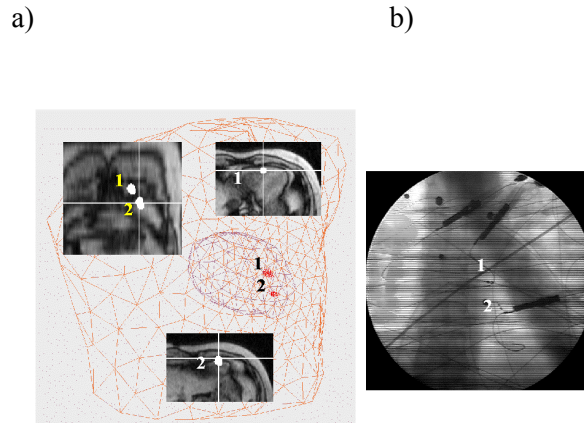


Figure 3: Same patient as in Fig. 2. a) ECD localization of the distal terminal of the two catheter projected onto frontal, lateral and axial MRI slices (white dots) and into a right anterior oblique projection of 3D BEM reconstruction of the patients torso and heart (red dots). b) frontal fluoroscopic image showing the position of the two amagnetic catheters.

4 Discussion

Current-density reconstruction and imaging from MCG data has recently shown very promising to identify and localize ischemic and viable myocardium [4-7, 9-11] as well as to localize ventricular arrhythmias [12], however clinical

validation of the spatial resolution of this novel imaging technique is still lacking.

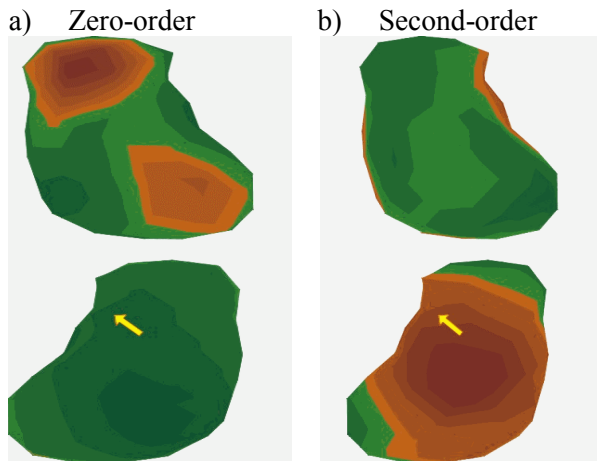


Figure 4 Patient # 162. Frontal (upper line) and posterior (lower line) views of epicardial surface. Current Density Imaging of a catheter-induced deep source (e.g. depolarization of left atrium from the coronary sinus). Comparison between results obtained with a) zero-order and b) second-order Tikhonov regularization methods. Only the latter is adequate to image the deep (14 cm from the sensors) dipolar source.

Computer simulation has shown that CDE can be accurate to localize both shallow and deep point-like or distributed sources and to separate simultaneous activation wavefronts [8]. In this study the AC technique has confirmed, in patients, the results of the simulation study. In particular a good agreement was found between CDE localization of single point-like dipolar sources with that obtained from the ECD inverse solution. Being the both equally effective in separating two catheter dipoles, activated in the right ventricle 3 cm apart (Fig. 2 and 3). Also this observation confirms simulation data [8]. This clinical validation added also evidence that the proper choice of the regularization method is crucial to separate shallow from deep cardiac sources, being the zero-order Tikhonov regularization more appropriate in focusing shallow sources and second-order regularization superior to localize deep sources (Fig. 4). Furthermore our results confirm that CDE can be used to localize currents in patients. Thus CDE is reliable to localize injury currents due to ischemia and arrhythmias [12] and has the potential for a new diagnostic approach to the arrhythmogenesis of CAD. In fact injury currents [10,16,17] are not detectable with ECG recordings, nonetheless they can be the trigger of otherwise unexplainable arrhythmias, through

“silent” electrotonic effect [18], (Fig. 5).

MCG-based CDE of ischemic injury currents from the same area where the site of onset of a focal arrhythmia is localized provides clinical evidence of electronically induced arrhythmias, up to now impossible.

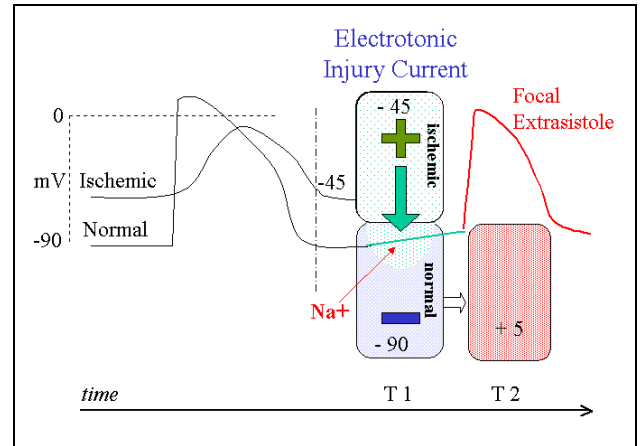


Figure 5. Schematic representation of the arrhythmogenic mechanism of electrotonic injury current. During electric diastole, the potential difference between the ischemic area (partially depolarized and therefore positive in respect of the surrounding healthy myocardium) and the normal tissue triggers the flowing of an electrotonic current. If such current reaches threshold, it induces the onset of a focal extrasystole which might initiate a sustained reentry tachycardia.

In conclusion CDE from multichannel MCG measurements can localize both shallow and deep point-like or distributed sources w/o the constraint of point-like source models (ECD). Interestingly this method seems to be rather insensitive to noise [8]. However, for clinical use, an automatic selection of the regularization method most appropriate for sources located at different depths is needed. Moreover the 3D model of the heart, used for CDE data presentation, should be more realistic (including the atria), tailored to the patient's heart with low cost input data (like fluoroscopic and echocardiographic imaging) and available on-line also during invasive EPS, with dimension comparable to fluoroscopy. CDE is promising in providing non invasively useful information of cardiac electrophysiological phenomena, with high diagnostic potential impact. The clinical validation of the method however warrants further investigation with a larger number of cases.

Acknowledgements

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